RESEARCH OBJECTIVES, OPPORTUNITIES AND FACILITIES FOR MICROGRAVITY SCIENCE

Presented by Robert J. Bayuzick
Office of Space Science and Applications
NASA Headquarters and Vanderbilt University

ABSTRACT

Microgravity Science in the U.S.A. involves research in fluids science, combustion science, materials science, biotechnology and fundamental physics. The purpose is to achieve a thorough understanding of the effects of gravitational body forces on physical phenomena relevant to those disciplines. This includes the study of phenomena which are usually overwhelmed by the presence of gravitational body forces and, therefore, chiefly manifested when gravitational forces are weak. In the pragmatic sense, the research involves gravity level as an experimental parameter.

Calendar year 1992 is a landmark year for research opportunities in low earth orbit for Microgravity Science. For the first time ever, three Spacelab flights will fly in a single year. IML-1 was launched on January 22; USML-1 was launched on June 25; and, in September, SL-J will be launched. A separate flight involving two cargo bay carriers, USMP-1, will be launched in October. From the beginning of 1993 up to and including the Space Station era (1997), nine flights involving either Spacelab or USMP carriers will be flown. This will be augmented by a number of middeck payloads and get away specials flying on various flights.

All of this activity sets the stage for experimentation on Space Station Freedom. Beginning in 1997, experiments in Microgravity Science will be conducted on Station. Facilities for doing experiments in protein crystal growth, solidification and biotechnology will all be available. These will be joined by middeck-class payloads and the microgravity glove box for conducting additional experiments. In 1998, a new generation protein crystal growth facility and a facility for conducting combustion research will arrive. A fluids science facility and additional capability for conducting research in solidification, as well as an ability to handle small payloads on a quick response basis, will be added in 1999. The year 2000 will see upgrades in the protein crystal growth and fluids science facilities. From the beginning of 1997 to the fall of 1999 (the “man-tended capability” era), there will be two or three utilization flights per year. Plans call for operations in Microgravity Science during utilization flights and between utilization flights. Experiments conducted during utilization flights will characteristically require crew interaction, short duration and less sensitivity to perturbations in the acceleration environment. Operations between utilization flights will involve experiments that can be controlled remotely and/or can be automated. Typically, the experiments will require long times and a pristine environment. Beyond the fall of 1999 (the “permanently-manned capability” era), some payloads will require crew interaction; others will be automated and will make use of telescience.
Microgravity Science and Applications Division
Research Objectives, Opportunities, and Facilities

Presented to:
Space Station Freedom Utilization Conference
August 3 - 6, 1992
Huntsville, Alabama

Robert J. Bayuzick

NASA Microgravity Program

OSSA Microgravity Science and Applications Division
Administers Microgravity Science Program

- NASA Research Centers
  - Universities
  - Industry
  - Government

Office of Commercial Programs
Facilitates the Commercial Use of Space

- Centers for Commercial Development of Space (CCDS)
  - Industry
  - Universities
  - Government
Program Goal

Develop a comprehensive research program in fluids science, combustion science, materials science, biotechnology, and fundamental physics for the purpose of attaining a structured understanding of gravity-dependent physical phenomena and those physical phenomena made obscure by the effects of gravity.

Fluid Dynamics and Transport Phenomena

- Multiphase flow and heat transfer
- Suspension/colloid/granular media mechanics
- Solid-fluid interface dynamics
- Capillary phenomena
- Magneto/electrohydrodynamics
- Transport phenomena
Combustion Science
Research Areas

- Ignition, smolder, solid materials
- Gaseous diffusion flames
- Gaseous premixed flames
- Heterogeneous (particles and droplets)
- Metals and combustion synthesis

Materials Science
Research Areas

Electronic and Photonic Materials
Metals and Alloys
Glasses and Ceramics

or

Crystal Growth
Solidification Fundamentals
Thermophysical Properties
Biotechnology Research Areas

- Cell physiology
- Cell differentiation
- Protein crystal growth
- Biological separations

Fundamental Physics Research Areas

- Critical point phenomena
- Gravitational physics
**FLIGHT OPPORTUNITIES -- THE PRESENT**

- Four MSAD missions in CY92:
  - **IML-1**  – successful mission: January 22 - 30, 1992
  - **USML-1**  – successful mission: June 25 - July 9, 1992
  - **Spacelab-J**
  - **USMP-1**
### International Microgravity Laboratory (IML-1) Microgravity Science and Applications Experiments

<table>
<thead>
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<th>Apparatus/Experiment</th>
<th>Acronym</th>
<th>Principal Investigator</th>
<th>Country of Origin</th>
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<td>OCGP</td>
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<td>- Heat and Mass Transport at the Critical Point</td>
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### U.S. Microgravity Laboratory (USML-1) Microgravity Science and Applications Experiments

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<td>- Drop Dynamics Investigation</td>
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**Microgravity Science Experiments**

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### U.S. Microgravity Payload (USMP-1)
**Microgravity Science and Applications Experiments**

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<td>- The Morphological Stability and In Situ Monitoring of Binary Alloy Solidification</td>
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### Microgravity Science and Applications Division Baseline Plan: 1994 - 2004

#### FUNDAMENTAL SCIENCE

- Lambda Point Experiment
- Critical Fluid Light Scattering Experiment
- Critical Fluid Viscoelastic Measurement Experiment
- Low Temperature Research Facility
- Satellite Test of Equivalence Principle

#### MATERIALS SCIENCE

- Metals and Alloys
- Glasses and Ceramics
- Electronic and Photonic Materials
- Crystal Growth Furnace
- Protein Crystal Growth

#### BIOTECHNOLOGY

- Cell Science
- Macromolecular Crystal Growth

#### SPACE MISSIONS

- Condensed Matter Physics
- Fluids & Transport Phenomena
- Combustion Science

#### SO & DA

- Space Acceleration Measurement System
- Crystal Acceleration Research Experiment

#### R & A

- Drop Tubes/Towers
- Parabolic Flights
- Sounding Rockets

#### ATD

- Advanced Furnace Technology
- Vibration Isolation Technology
- Non-Contact Temperature Measurement
- Laser Light Scattering Experiment
- Interface Measurements

#### Microgravity Science and Applications Division Planning Manifest

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<th>CY92</th>
<th>CY93</th>
<th>CY94</th>
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**NOTES:**
- *Launch Redundancy Dates and STS flight numbers from SSP Baseline Manifest, Mar. 20, 1992*
- *Launch Date*
- *(I) indicates non-U.S. hardware on which U.S. investigators are flying (International)*
- *(U) indicates U.S. non-MSAD hardware in which MSAD investigators are flying*
- *Enhanced/Upgraded version*
- *Will not fly if Space Station is available*
- *Candidate transition hardware*
### Microgravity Science and Applications Division Planning Manifest

#### CY96

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<thead>
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Microgravity Science and Applications Division

Planned Research Announcements

Calendar Year: 91 92 93 94 95 96 97

Combustion Science

Biotechnology

Fluids and Transport

Materials Science

Fundamental Science

Ground-Based Research

Combustion

Biotechnology

Fluids and Transport

Materials Science

Fundamental
Microgravity Science and Applications Division FY92 Budget by Program

- Science: $1,995K
- Biotechnology: $2,183K
- Protein Crystallization Growth (PCG): $4,761K
- Containerless: $14,908K
- Advanced Infrastructure Technology Development (ATD): $1,970K
- HQ & Center Support: $26,596K
- Research and Analysis (R & A): $16,500K
- Fundamental Science: $9,147K
- Fluids: $9,658K
- Combustion: $6,810K

Total: $120,800K

Microgravity Science and Applications Space Station Facilities
Integrated Launch Schedule

Overall Flight Sequence

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Utilization Flight Increment

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13 Days Shuttle Docked at Space Station Freedom

MSAD Space Station Payload Traffic Model (April 1992)

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<tr>
<td>SSF-Provided Microgravity Glovebox</td>
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* SAMS SSSF is Station unique hardware, not transition hardware

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Protein Crystal Growth
Science Utilization

- Evaluate the effects of gravity on the growth of protein crystals
- Study physics/dynamics of macromolecular crystal growth
- Support biotechnology research by growing high quality macromolecular protein crystals which can be used for x-ray crystallography

Protein Crystal Growth Program Evolution

**PCG (current)**
Protein Crystal Growth
Middeck Refrigerator/Incubator Module with Vapor Diffusion Apparatus

**APCG (1993 - 1997)**
Advanced Protein Crystal Growth
Middeck using Thermal Enclosure System (TES) for PI-specific crystal growth hardware

**APCG transition (1997)**
TES units modified for flight in SSF

Advanced Protein Crystal Growth Facility for SSF
Host Facility for Advanced Thermal Enclosures, PI-specific Crystal Growth Hardware
Advanced Protein Crystal Growth (APCG) Payload Description (1997 - 1998)

- **Power**: 0.5 kW nominal/1 kW peak
- **Mass**: 300 kg
- **Volume**: 1 rack

**TRANSITION HARDWARE**

2 Thermal Enclosure System (TES) units with crystal growth apparatus
SSFP provides adapter hardware, integration

- APCG plans to accommodate second generation crystal growth hardware in TES units
  - Vapor Diffusion Apparatus
  - Thermally-controlled batch process
  - Liquid-liquid diffusion
  - Dynamically-controlled systems
- Automated experiment initiation and deactivation


- **Power**: 2.1 kW nominal/2.4 kW peak
- **Mass**: 616 kg
- **Volume**: 1 rack

Space Station-unique hardware
Advanced thermal enclosures
Enhanced diagnostic systems with imaging capability

- Third generation protein crystal growth hardware
  - May accommodate a larger number of experiments than APCG by using advanced thermal enclosures
  - Can accommodate current TES, new thermal enclosures, or PI-supplied thermal enclosures for long-duration crystal growth, and enhanced diagnostics
  - Automated experiment initiation and deactivation
- Gain understanding of the mechanisms which correlate directional solidification parameters and materials properties for various technologically important materials
- Explore potential for utilization of low gravity environment to develop unique materials or materials structures which have unique, crafted properties
- Measure thermophysical properties of materials
Space Station Furnace Facility/Crystal Growth
Furnace Payload Description
(1997 - 1998)

- Power  2.0 kW nominal/4.0 kW peak
- Mass  1050 kg
- Volume  2 racks
  1 Rack - Core  Space Station-unique controls, power conditioning and diagnostics
  1 Rack  CGF furnace
   - Pressure vessel with flexible glovebox
   - Reconfigurable furnace module
   - Furnace translation mechanism
   - Automated sample exchange mechanism (up to six samples)

- Gradient zone thickness can be optimized before launch, and a heat extraction plate can be included to obtain steeper gradients
- Interface demarcation will be available by mechanical and current pulsing

Space Station Furnace Facility (SSFF)

- Power  6.5 kW nominal/9.0 kW peak
- Mass  1,350 kg
- Volume  3 racks
  1 Rack - Core  Space Station-unique controls, power conditioning and diagnostics
  1 Rack  Furnace Module 1
  1 Rack  Furnace Module 2

- Furnace Modules – to be determined from NASA Research Announcement/Announcement for Opportunity (NRA/AO) selection -- first PI selections in August 1992
- Modules being considered
  - Upgraded programmable Multi-Zone Furnace (used for planning purposes)
  - Transparent Furnace
  - Bridgman with Quench
  - Float-Zone Crystal Growth Furnace
Combustion Research Science Utilization

- Provide better understanding of fundamental theories of combustion processes and phenomena, such as:
  - Premixed gaseous fuel combustion
  - Laminar and turbulent diffusion flames
  - Flame spreading and smoldering with solid fuels
  - Flame spreading over liquid pools
  - Effectiveness of fire extinguishing techniques
  - Droplet, particle, and spray combustion
  - Metals combustion

- Provide scientific and engineering data for a variety of combustion related applications, such as spacecraft fire safety
Advanced Combustion Middeck Payload

- Power: 120 W
- Mass: 400 kg
- Volume: 4 middeck lockers

- A CoDR was held in December 1991
- Will have the capability to do multiple experiment samples intensified video for low luminosity
- Studying the capability for chamber atmosphere clean-up


- Power: 1.5 kW nominal/2.3 kW peak
- Mass: 1,400 kg
- Volume: 2 racks

**TRANSITION HARDWARE**

1 Rack - Core: Shares a common core with the fluids module
1 Rack - Module 1: Combustion experiment rack

- The combustion experiment rack will house a generic combustion chamber with investigation-specific equipment:
  - Nozzles for burning of gases
  - Sample holders for solid fuels experiment
- The combustion chamber will have ports to accommodate different modular diagnostics systems:
  - CCD video system
  - Infrared imager
  - Schlieren imaging system
  - Temperature measuring probes
  - Gas sampling probes
Modular Combustion Facility (MCF)
Payload Description (2001+)

- **Power**: 5 kW nominal/7.1 kW peak
- **Mass**: 1,400 kg
- **Volume**: 2 racks

**Station-Unique Hardware**

1 Rack - Core
- Core 2 shared with fluid modules

1 Rack - Module 2 - combustion experiment rack

- Module 2 to be determined from NRA/AO selection
- Two candidate experiment racks under study
  - Quiescent Combustion Chamber
  - Low-Speed Combustion Tunnel

Fluid Physics and Dynamics
Science Utilization

- Provide advances in theories of fluid physics
- Provide improvements in thermophysical property measurement
- Provide scientific and engineering data related to fluids-related applications and systems
- Experiments may cover a broad area of interest:
  - Isothermal-isosolutal capillary phenomena
  - Capillary phenomena with thermal/solutal gradients
  - Thermal solutal convection and diffusive flows
  - First order phase transitions in a static fluid
  - Multi-phase flow
**Fluids Program Evolution**

**EES (1985, 1992)**
Fluid Experiment System
Spacelab, multi-user

Surface Tension Driven Convection Experiment
Spacelab, PI-specific

Pool Boiling Experiment
Get-away special payload, PI-specific

**AEM (1999)**
Advanced Fluids Module for SSF
Multi-user module added to Fluids/Combustion core facility

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**Fluid Physics Dynamics Facility (FPDF)**
Payload Description (1999+)

- **Power**
  - Fluids Module 1:
    - 2.0 kW nominal/3.0 kW peak
  - Fluids Module 2:
    - 5.9 kW nominal/9.5 kW peak

- **Mass**
  - 700 kg

- **Volume**
  - 1 rack

  1 Rack
  Fluids Module-1 (1999)
  Changed out for
  Fluids Module-2 (2000)

- **Modules 1 and 2** -- to be determined by AO/NRA selection

- **Two candidate experiment racks under study**
  - Support dynamic fluid experiments in a multi-phase apparatus
  - Vibration isolation containment enclosure for sealed-cell experiments
- Accommodate experiments requiring the positioning and manipulation of materials without physical contact with container walls.
- Conduct research on properties and phenomena that on Earth are seriously affected by container contamination, container-generated nucleations, and gravity effects.

Containerless Program Evolution

**SAAL (1983, 1985)**
Single Axis Acoustic Levitator
Cargo-bay, PI-specific

**DDM (1985)**
Drop Dynamics Module
Spacelab, PI-Specific

**DFM (1992)**
Drop Physics Module
Spacelab, multi-user
Modular concept, precursor for SSF facilities

**MCPE (under review)**
Modular Containerless Processing Facility for SSF
Host facility for modular, inter-changeable levitators
- Electromagnetic
- Electrostatic
- High Temp Acoustic
Modular Containerless Processing Facility (MCPF) Payload Description (under review)

- **Power**: 2.5 kW nominal / 3.0 kW peak
- **Mass**: 700 kg
- **Volume**: 1 rack

Sample positioning devices
Diagnostics and control

- Levitation modules to position the sample may be electrostatic, electromagnetic, acoustic fields, or a hybrid combination
- Gain understanding in vast area of physical sciences ranging from the behavior of liquid drops in space, the measurement of thermophysical properties of materials, and the characterization of metals, glasses, and ceramics heated to temperatures up to 2700°C

Biotechnology
Science Utilization

- Study cell function and differentiation in a low mechanical stress environment
- Culture end-differentiated tissue models for studies of genetic regulations
Biotechnology Program Evolution

**IEF (1984, 1988)**
Isoelectric Focusing
Middeck, PI-specific

Phase Partitioning Experiment
Middeck, PI-specific

**RTE (1997)**
Biotechnology Facility for SSF
Host Facility for future investigations in:
- Cell culturing
- Cell separations
- Future areas of Biotechnology

**Bioractor (1991)**
Rotating wall cell culturing system
Middeck, multi-user
Awaiting results of 1991
Biotechnology NRA to determine future flight development

**Biotechnology Facility Payload Description (1997+)**

- **Power**: TBD kW nominal and peak
- **Mass**: 700 kg
- **Data**: TBD Kbits/sec
- **Volume**: 1 rack

- The BTF will accommodate a series of PI-developed, self-contained biotechnology experiments. BTF "services" will include power conditioning and distribution, video and data processing, and basic gases and fluids.
- Concept may serve as the basis for a Small and Rapid-Response (SRR) Payload (1999)
"Middeck Class" Payloads (1997+)

- Power TBD kW nominal and peak
- Mass TBD
- Data TBD Kbits/sec
- Volume 2 racks

**TRANSITION HARDWARE**
Middeck-class experiments
SSFP provides adapter hardware, integration

- The SSFP-provided Middeck Class Payload Adapter (MDC) will host a series of small to moderate-scale microgravity experiments by providing an interface that emulates the Shuttle middeck.

  Experiments in Fluids and Transport Phenomena, Combustion, Materials Science

- MDC Accommodations will be similar to those provided by the SSFP interface hardware used for the APCG Transition Payload

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SSFP-Provided Microgravity Glovebox (1997+)

- Power TBD kW nominal and peak
- Mass 700 kg
- Data TBD Kbits/sec
- Volume 1 rack

- The SSFP-Provided Materials Science Glovebox (MSG) provides an enclosed work space isolated from the SSF ambient environment for handling microgravity science samples and hardware.

- The MSG will accommodate a series of small-scale microgravity science experiments and technology demonstrations.

- MSG services will include video and film cameras with appropriate lighting, temperature control and heat rejection. In the work volume, power outlets for use by experiments and apparatus for recovering fluid spills.
Utilization Flights

- All Microgravity Science and Applications Division (MSAD) payloads plan to operate during utilization flights
- Some operations will be very similar to Spacelab
  - High-speed film cameras for data storage
  - Discipline-emphasis crew skills
- Operations unlike Spacelab
  - On-orbit rack changeout
  - Logistics/resupply (gases), sample harvesting, and changeout for return
  - Experiment set up for ground-tended runs

Unmanned Operations

- All MSAD payloads except combustion plan to operate during ground-tended operations
- Payloads will require uplink communications
  - For initiating run sequences
  - Power on/off
  - Restart experiment run
- Payloads will require downlink
  - Monitoring experiment runs
  - Health and safety
  - Quick-look analysis
Operational Intent of MSAD-MTC

- Two to three 16-day utilization flights each year
- **Operation of facilities during utilization flights**
  - Experiments requiring crew interaction
  - Shorter duration experiments
  - Experiments that are less sensitive to "noisy" acceleration environment
- **Operations between utilization flights (ground-tended periods)**
  - Experiments that can be controlled remotely and/or automated
  - Longer duration experiments
  - Experiments requiring a pristine environment
- **Operations during assembly flights**
  - Conducted on a non-interference basis
  - May be limited to changing out samples and setting up experiments to be initiated later

Operational Intent of MSAD-PMC

- **Payloads requiring crew interactions**
- **Automated payloads utilizing telescience methods**
- **Crew time is a limited resource**
Science return from MSAD payloads will begin in 1997 after launch of the U.S. Laboratory and will continue through 2000+
- MSAD plans to conduct a broad range of experiments during the unmanned periods prior to PMC, during utilization flights, and PMC and beyond on SSF.

Science operations conducted during the utilization flights will be similar to Spacelab flights except for the added tasks of collecting and securing of samples, experiment setup for unmanned runs, and rack/module equipment changeout.

Unmanned operations will require automation of payloads and telescience but minimal two-way communications between MSAD payloads and the ground is intended.

- Active, growing, diverse program
- Areas of research
  - Biotechnology
  - Combustion
  - Fluids Science
  - Fundamental Physics
  - Materials Science
- Continuing to find new experimental possibilities
  - Encouraging science community to participate
  - Soliciting science proposals through NRA's
  - Facilitating their development
- Collaborating with the international science community
  - Sharing use of facilities
- Looking forward to an exciting decade in microgravity research
Back Up Charts

Science Planning Process

- Community involvement in the program
  - Four DWG's plus Microgravity Subcommittee to Space Science and Applications Advisory Committee (SSAAC)

- National Academy of Sciences
  - Microgravity Science Committee of the Space Studies Board
    -- Established in 1988
    -- First meeting in 1990
  - Development of long-term strategy for microgravity sciences

- Integrate microgravity initiatives into OSSA program
  - SSAAC review and advice
  - OSSA Strategic Plan
Chairperson
William A. Sirignano (6/94)
Dean, School of Engineering
University of California at Irvine
[Combustion]

Richard C. Hart
Space Studies Board
National Academy of Science

Robert A. Brown (6/92)
Head of Chemical Engineering
Mass Institute of Technology
[Fluid Dynamics & Elec Mats Model]

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Rensselaer Polytechnic University
[Metals]

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United Technologies Research Center
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Fluids & Transport DWG Chair

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Department of Materials Science and Engineering
University of Wisconsin
Materials Science DWG Chair

Simon Ostrach
Department of Mechanical and Aerospace Engineering
Case Western Reserve University

Alexander Mcpherson
Department of Biochemistry
University of California

Membership of Microgravity Science and Applications Subcommittee (MSAS)

Chair: Dudley Saville
Chemical Engineering Department
Princeton University

Exec. Secretary: Roger Crouch
NASA Headquarters
MSAD Chief Scientist

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Center for Advanced Research in Biotechnology
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Dept. Aerospace Engineering
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University of Wisconsin
Materials Science DWG Chair

Simon Ostrach
Department of Mechanical and Aerospace Engineering
Case Western Reserve University

Alexander Mcpherson
Department of Biochemistry
University of California
### MEMBERS

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### Discipline Working Groups

- **Biotechnology**
  - Chair: Dr. Gary Gilliland (NIST)
  - Vice-Chair: Dan Carter (MSFC)

- **Combustion**
  - Chair: Dr. Gerard Faeth (University of Michigan)
  - Vice-Chair: Kurt Sacksteder (LeRC)

- **Fluids and Transport**
  - Chair: Stephen H. Davis (Northwestern University)
  - Vice-Chair: Bob Thomson (LeRC)

- **Materials Science**
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University of Wisconsin at Madison

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Space Science Laboratory
NASA Marshall Space Flight Center

Prof. Tim Anderson
Dept. of Chemical Engineering
University of Florida at Gainesville

Dr. Richard Hopkins
Science and Technology Center
Westinghouse Electric Corporation

Dr. Reid Cooper (ad hoc assignment)
Dept. of Metallurgical and Materials Engineering
University of Wisconsin at Madison

Dr. Robert Schaefer
Materials Science and Engineering Laboratory
National Institute of Standards and Technology

Prof. Jonathan Dantzig
Dept. of Chemical and Materials Engineering
University of Wisconsin at Madison

Dr. Rohit Trivedi
Ames Laboratory
Iowa State University

Prof. Dennis Readey
Dept. of Metallurgical and Materials Engineering
Colorado School of Mines

Prof. Peter Voorhees
Dept. of Materials Science and Engineering
Northwestern University

Dr. John Hurt
Division of Materials Research
National Science Foundation

ESI Representative
Dr. Jean Jacques Favier
CEREM/DEM - Section d'Etudes de la Solidification et de la Cristaigenese, Grenoble

Fluid Dynamics Discipline Working Group

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Northwestern University

Dr. Robert Thompson (Vice-Chair)
NASA Lewis Research Center

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Dept. of Physics
University of Oregon

Prof. Paul Nietzel
School of Mechanical Engineering
Georgia Institute of Technology

Dr. John Huang
Exxon Research and Engineering Company

Prof. Harry Swinney
Dept. of Physics
University of Texas at Austin

Prof. Richard Lahey
Dept. of Nuclear Engineering and Engineering Physics
Rensselaer Polytechnic Institute

ESI Representative
Prof. Y. Mainjeac
Director de la Strategie et de l'Evaluation Centre d'Etudes Nucleaires de Grenoble

Prof. Michael Moldover
Center for Thermodynamics and Molecular Science
National Institute of Standards and Technology
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Discipline Working Group

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Dept. of Aerospace Engineering
University of Michigan

Mr. Kurt Sacksteder (Vice-Chair)
NASA Lewis Research Center

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College of Engineering
Mississippi State University

Prof. Robert Santoro
Mechanical Engineering Dept.
Pennsylvania State University

Dr. Raymond Friedman
Factory Mutual Research

Prof. Mitchell Smooke
Dept. of Mechanical Engineering
Yale University

Prof. Jack Howard
Dept. of Chemical Engineering
Massachusetts Institute of Technology

Prof. Forman Williams
Applied Mechanical and Engineering Science Dept.
University of California at San Diego

Prof. C. K. Law
Dept. of Mechanical and Aerospace Engineering
Princeton University

ESA Representative
Dr. L. Gokalp
CNRS - Laboratoire de Combustion et Systemes Reactifs, Orleans

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Center for Advanced Research in Biotechnology
National Institute of Standards and Technology

Dr. Daniel Carter (Vice-Chair)
NASA Marshall Space Flight Center

Dr. Colette Freeman
Division of Cancer Biology, Diagnosis, and Centers
National Cancer Institute

Dr. F. L. Suddath
Vice-President for Information Technology
Georgia Institute of Technology

Dr. Scott Power
Director of Biochemistry
Genencor International

Dr. Patricia Weber
Central Research and Development Dept.
Dupont-Merck Pharmaceutical Company

Prof. Lola Reid
Dept. of Molecular Pharmacology
Albert Einstein College of Medicine

ESA Representative
Prof. P. G. Pighetti
Università di Milano, Departmento di Scienze e Technologie Biomediche, Sez. Chimica Organica, Milano
Membership of Discipline Working Groups (DWG's)

**DWG**

\[ 8 - 12 \text{ members} \]

- Chair
- Ex Officio Member
- Vice-Chairperson
- 4 Members
- Member

- Unaffiliated (desired)
- Discipline Program Scientist
- Center Scientist
- Principal Investigator(s) (2 maximum)
- Industry
- Academia
- Other Government

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